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The Charge (Z) Identification Module (ZIM) for ACCESS: An Instrument Calibration using 10.6 GeV/nucleon $_{79}$Au

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Abstract

We report the results of an accelerator calibration of detectors planned for use in the ZIM experiment for ACCESS. The experiment utilizes silicon detectors to measure dE/dx, and aerogel and acrylic Cherenkov counters for velocity measurements. For a $_{79}$Au beam with energy 10.6 GeV/nucleon, we obtain resolution in charge for the silicon, acrylic Cherenkov, and aerogel Cherenkov of 0.20, 0.22, and 0.45 cu respectively.

1 Introduction:

The Z-Identification Module (ZIM), which is one component of the ACCESS program for the International Space Station, is designed to measure the abundances of all of the elements with $10 \le Z \le 83$ with excellent resolution and good statistics. The broad science goals are to address questions of cosmic ray origin, acceleration, and diffusion through the galaxy from the source to Earth. Our current knowledge of the elemental abundances of cosmic ray nuclei with $Z>32$ has been obtained primarily from the HEAO-3 C3 experiment (Binns et al., 1989), the Ariel-6 experiment (Fowler, et al., 1987), the LDEF experiment (Keane, et al., 1997) and recently by the TREK experiment (Westphal, et al., 1998). Although these experiments have yielded valuable insights into the key questions that can be addressed by cosmic ray studies, limitations in their elemental resolution and charge range coverage (TREK) make it important to perform an experiment that can make high resolution measurements for every element in this charge range using a single instrument. This will make it possible to tie elemental abundances over a large range of atomic number together in a continuous fashion, thus avoiding problems of normalization between separate experiments, and enabling the comparison of abundance patterns over large charge ranges with model predictions.

2 Instrument

The ZIM instrument (Binns et al., 1997) consists of silicon detectors located on top and near the bottom of the stack to measure dE/dx and to check for interactions in the instrument, two Cherenkov counters with different refractive index (Acrylic (C1), n=1.5, and Aerogel (C0), n=1.04) to measure velocity, and a scintillating fiber hodoscope to measure particle trajectory. Cherenkov counters with different refractive index are used to eliminate the ambiguity in charge determination due to charge contour cross-over, which can occur in dE/dx-C experiments that utilize a single Cherenkov counter (Binns et al., 1989). This technique enables us to subdivide cosmic rays into three separate energy classes: low energy nuclei in

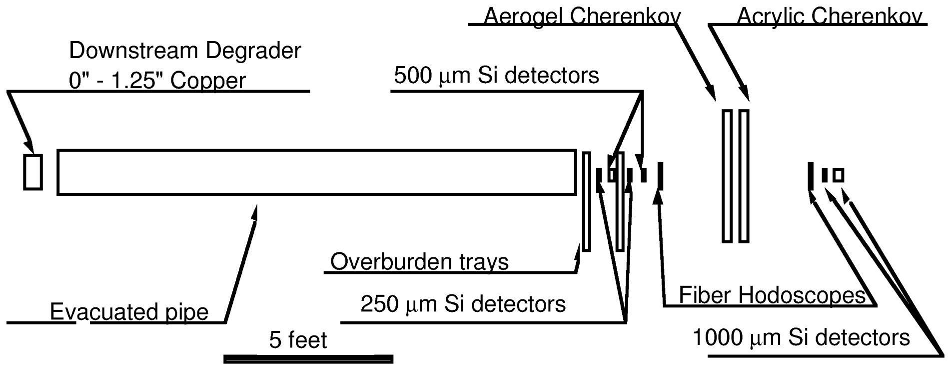

Fig. 1--Experiment Setup at Brookhaven

which the aerogel signal is below Cherenkov threshold (C0/C1≤0.1), medium energy for which the aerogel signal is above threshold but has not yet reached saturation (0.1<C0/C1<0.9), and high energy for which the aerogel signal is near saturation (C0/C1≥0.9). In this paper we describe the results of an accelerator calibration that was conducted at Brookhaven National Laboratory in 1998. The primary beam was $_{79}$Au with full beam energy 10.6 GeV/nuc. For some of the runs the beam was degraded by passing it through various thicknesses of absorber material to obtain lower energy particles, which enabled us to explore the energy dependence of our detectors, and to obtain a fragmented beam so that we could study multiple charges simultaneously. The beam test experiment setup is shown in Fig. 1. There were 6 silicon detectors (S0-S5), an acrylic light collection box Cherenkov counter, an aerogel Cherenkov counter, and two coded fiber hodoscopes (H0, H1). The dimensions of the light collection boxes were 1.15m square and a false ceiling was installed (depth 10.5 cm) and part of the PMT photocathode area was masked off to provide the same aspect ratio as is planned for the ZIM flight counter. The charge resolution measurements obtained with these counters thus should be comparable to that which would be obtained with the full size ZIM instrument. The silicon detectors were Li-drifted silicon with thicknesses shown in Fig. 1. The fiber hodoscope consisted of 4 fiber layers (2-x and 2-y), with each layer having 100 1mm square cross-section fibers. Each set of 100 fibers were coded and read out by 10 photomultiplier tubes located at either end of the layer. The fibers were coded such that a fiber hit recorded by simultaneous PMT signals at both ends of each layer gives a unique identification of the fiber traversed by the particle (Lawrence, et al., 1999).

3 Data:

In Fig. 2 we show a histogram of a 10.6 GeV/nucleon $_{79}$Au beam fragmented by passing it through a 1 inch thick plexiglass plate. The data are from a sum of the signals on the front two silicon detectors with a total thickness of 750μm. The gold peak which extends on the vertical scale to ~1700 counts is cut off to emphasize the excellent resolution and separation between adjacent nuclei. The charge resolution obtained is 0.20 cu.

Figs. 3 and 4 show plots of one of the silicon detectors (S1) plotted vs. the acrylic and aerogel Cherenkov counters respectively. Each point gives the mean and sigma of the peak in the silicon and Cherenkov detectors for various monoenergetic $_{97}$Au beams from 10.6 GeV/nucleon down to below minimum ionizing. The curve through the data points has been scaled by $(80/79)^2$ and $(78/79)^2$ to indicate where data for $_{78}$Pt and $_{80}$Hg would lie. We see the general behavior expected for dE/dx vs. C, except that the relativistic rise in the silicon signal (extreme right of each contour) does not extend up as far as would be the case for a thick dE/dx detector. This is because the thin silicon detector measures energy deposit, not total energy loss in the detector. As the particle energy increases, the number of high-energy knock-on electrons increases as dE/dx increases, but they deposit only a fraction of their energy in the thin silicon detectors. If cosmic rays did not have higher energy than 10.6 GeV/nucleon, then it would probably not be

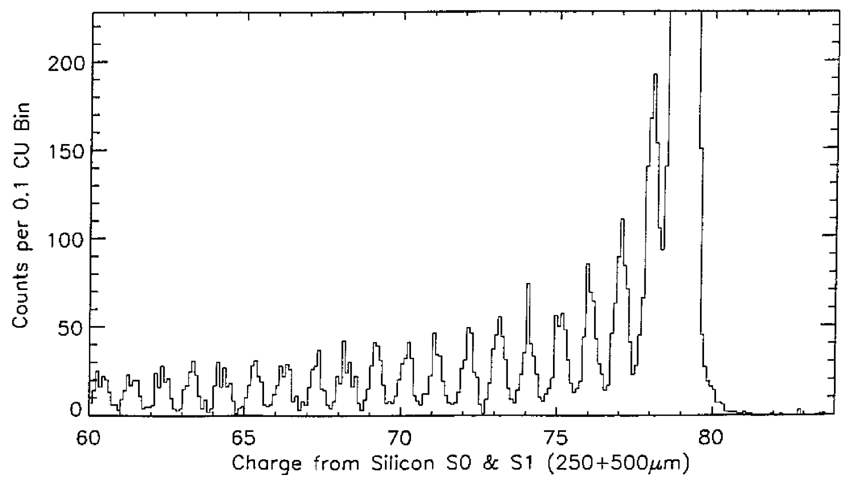

Fig. 2--Histogram of summed signals from two front silicon detectors.

necessary to have a second Cherenkov counter with different refractive index. However, since the cosmic-ray beam will have significant numbers of higher energy nuclei, it is likely that the silicon signal will continue to rise to some extent with energy and some ambiguity between adjacent elements may result. The resolutions shown in Figs. 3 and 4 (error bars) are not as good as that shown in Fig. 2 because we are plotting data from a single detector with thickness 500 μm instead of two detectors with total thickness of 750 μm used in Fig. 2. In addition, for the lower energies in Fig. 3, there appears to be significant

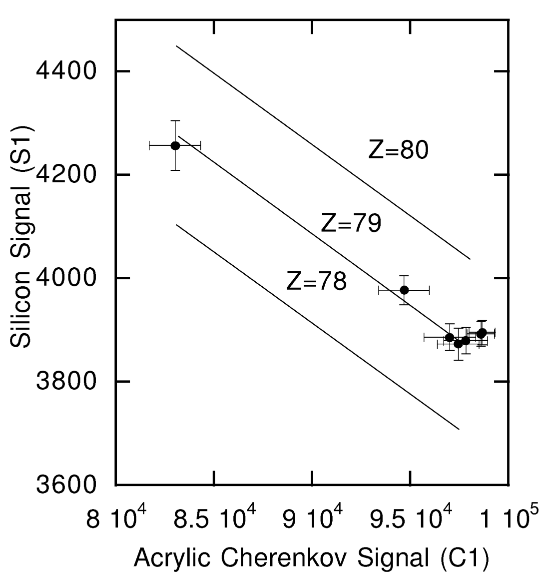

Fig. 3--Silicon vs. Acrylic Cherenkov Signals

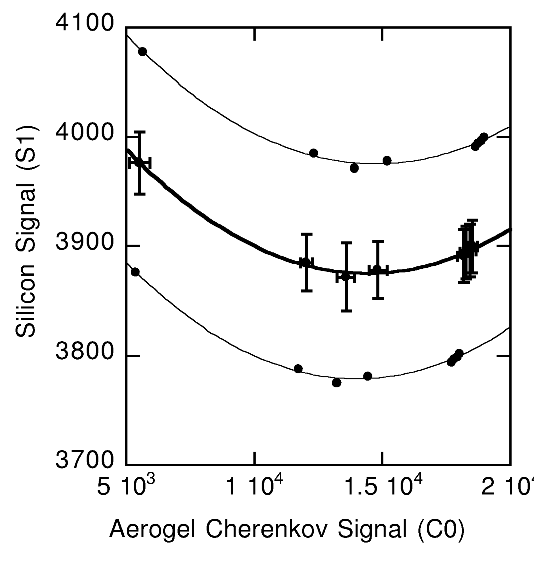

Fig. 4--Silicon vs. Aerogel Cherenkov Signals

broadening in resolution which is likely due to knock-ons from the large amount of absorber (downstream absorber) used to obtain the lower energies. The resolution obtained for the full beam energy of the acrylic and aerogel Cherenkov counters was 0.22 and 0.45 cu respectively (not shown). We note that the silicon and acrylic counters are used for charge identification, while the aerogel signal is used to determine which energy range the particle falls in as well as providing a small velocity correction to particles in the intermediate energy range (Fig. 4).

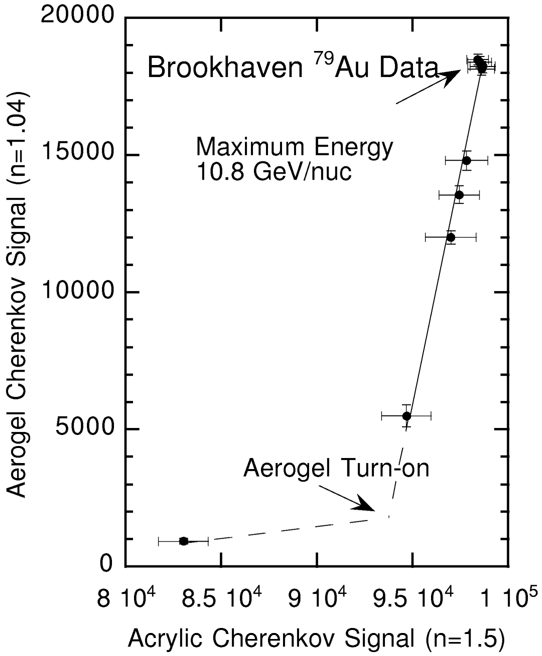

Fig. 5--Aerogel vs. Acrylic Cherenkov Signals

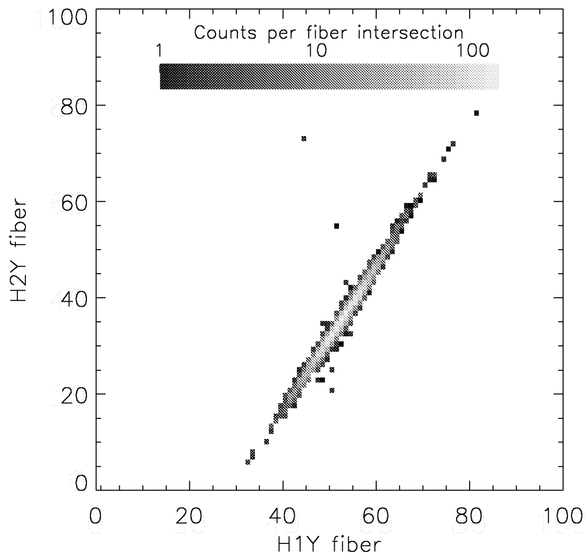

Fig. 6--Crossplot of hodoscope fibers

In Fig. 5 we show a plot of the aerogel vs. acrylic Cherenkov signals. We see that at low energies the aerogel signal is near zero. As the particle energy exceeds the aerogel Cherenkov threshold, it "turns on" and increases as we go to the full beam energy. It is this turn-on of C0 that is used to discriminate between the three energy regions of interest.

Fig. 6 is a cross plot of the front fiber hodoscope y-fiber hit vs. the rear hodoscope y-fiber hit. The linear correlation and the breadth of the distribution shows that the resolution in position is ≤1 mm. This spatial resolution is sufficient that the uncertainty in position will not significantly affect the overall charge resolution of ZIM.

4 Conclusions:

We have calibrated a test model of the ZIM experiment and have determined that the resolution in charge that can be obtained is sufficient to achieve the goal of resolving every element over the charge range of $10 \leq Z \leq 83$.

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